

THE ISRU FIELD TESTS 2010 AND 2012 AT MAUNA KEA, HAWAII: RESULTS FROM THE MINIATURISED MÖSSBAUER SPECTROMETERS MIMOS II AND MIMOS IIA. G. Klingelhöfer¹, R.V. Morris², M. Blumers¹, B. Bernhardt³, T. Graff^{2,4}. ¹Johannes Gutenberg Universität Mainz, Institut für Anorganische und Analytische Chemie, Staudinger Weg 9, Mainz, Germany. ²NASA Johnson Space Center, Houston, TX, USA. ³Von Hoerner&Sulger GmbH, Schwetzingen, Germany. ⁴Jacobs Engineering, Houston, TX, USA.
klingel@mail.uni-mainz.de

Introduction: The 2010 and 2012 In-Situ Resource Utilization Analogue Test (ISRU) [1] on the Mauna Kea volcano in Hawai'i was coordinated by the Northern Centre for Advanced Technology (NORCAT) in collaboration with the Canadian Space Agency (CSA), the German Aerospace Center (DLR), and the National Aeronautics and Space Administration (NASA), through the PISCES program. Several instruments were tested as reference candidates for future analogue testing at the new field test site at the Mauna Kea volcano in Hawai'i. The fine-grained, volcanic nature of the material is a suitable lunar and martian analogue, and can be used to test excavation, site preparation, and resource utilization techniques. The 2010 location *Pu'u Hiwahine*, a cinder cone located below the summit of Mauna Kea (19°45'39.29" N, 155°28'14.56" W) at an elevation of ~2800 m, provides a large number of slopes, rock avalanches, etc. to perform mobility tests, site preparation or resource prospecting. Besides hardware testing of technologies and systems related to resource identification, also *in situ* science measurements played a significant role in integration of ISRU and science instruments.



Fig. 1: The ISRU test location at Mauna Kea, Hawai'i

The Mössbauer spectrometers MIMOS II and MIMOS IIA: The Miniaturised Mössbauer Spectrometers MIMOSII and MIMOS IIA are contact instrument for placement on rock or soil samples (no sample preparation). MIMOS II instruments are on board the two NASA MER rovers on the surface of

planet Mars since January 2004 and still functional after more than 7 years [2–5], and have been on board the Russian 2011 Phobos-Grunt mission. An advanced Mössbauer instrument MIMOS IIA has been developed for future ESA and NASA rover missions. Major improvements are the simultaneous acquisition of Mössbauer (MB) and XRF spectra, with highest energy resolution in the XRF mode allowing very precise determination of elemental composition [6–7]. MIMOS IIA is using newly designed Si-Drift detectors (SDD) with circular geometry [6,7].

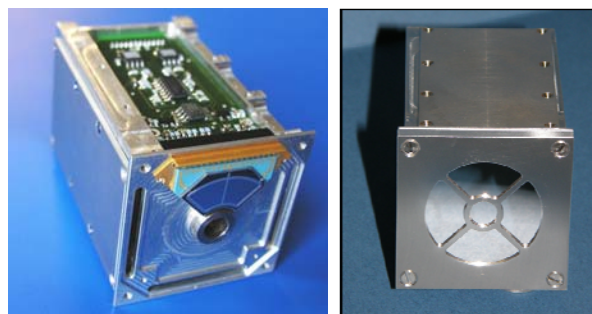


Fig. 2: (left) MIMOS IIA sensorhead with one of the four SDD quarters of the new ring detector and double preamplifier. Dimensions of the sensorhead are nearly identical to MIMOS II. (right) MIMOS IIA sensorhead with cover and very thin but light-tight x-ray window.

The active area per SDD segment is $2 \times 45 \text{ mm}^2$. Fig. 2 shows the MIMOS IIA sensorhead without cover, equipped with one of the four SDD segments. The energy resolution at 5.9 keV is $< 280 \text{ eV}$ at room temperature and 131 eV FWHM at -40°C , resulting in an significant increase of the signal to noise ratio (SNR) and reduction of the integration time of Mössbauer measurements by a factor up to 10.

In addition to the Mössbauer analysis simultaneous acquisition of the X-ray fluorescence spectrum provides data on the sample's elemental composition [7]. At room temperature and normal pressure the detection of X-rays down to $\sim 1 \text{ keV}$ is possible.

During the field test the instruments MIMOS II and MIMOS IIA were mounted on the robotic arm of the NORCAT rover system (see Fig. 3). Fig. 4 shows XRF spectra obtained in-situ with MIMOS IIA for three different samples at the 2010 test site. The *dark*

soil sample and the *Massive Basalt* sample clearly contain significant amounts of Ca and Ti (peaks between 3 keV and 5 keV) besides Fe (~ 6.4 keV). The sample *Olivine Xenolith* does not contain Ca and Ti (as expected).



Fig. 3: Combined Mössbauer/XRF-MIMOS IIA mounted on the robotic arm of the NORCAR rover.

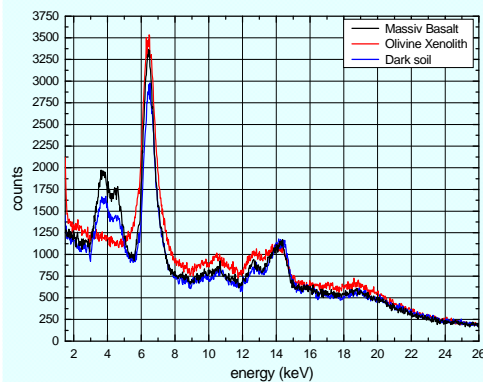


Fig. 4: XRF spectra taken with the MIMOS IIA instrument for three ISRU samples. Measurements were done in situ using the robotic arm of the rover for deployment. The temperature during acquisition was about +5 C. Between 3 keV and 5 keV the Ca and Ti peaks are visible, and at 6.4 keV the Fe peak.

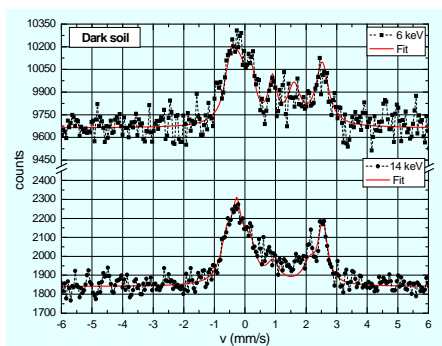


Fig. 5.a: 6.4 keV and 14.4 keV Mössbauer spectrum taken with the MIMOS IIA instrument for the *Dark Soil* sample (see also Fig.4).

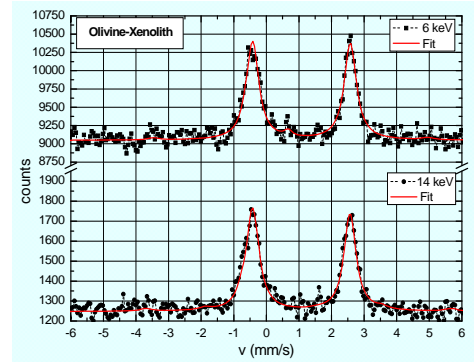


Fig. 5.b: 6.4 keV and 14.4 keV Mössbauer spectrum taken with the MIMOS IIA instrument for the *Olivine-Xenolith* sample (see also Fig.4).

In Fig. 5.a and 5.b the corresponding Mössbauer spectra of two samples from Fig.4 are shown. The 6.4 keV and 14.4 keV MB data have been obtained simultaneously with the XRF data.

Summary: For the advanced Mössbauer instrument MIMOS IIA, the new detector technologies and electronic components increase sensitivity and performance significantly. In combination with the high energy resolution of the SDD it is possible to perform X-ray fluorescence analysis simultaneously to Mössbauer spectroscopy. In addition to the Fe-mineralogy, information on the sample's elemental composition will be gathered.

The 2010 and 2012 field campaigns demonstrated that in-situ Mössbauer spectroscopy is an effective tool for both science and feedstock exploration and process monitoring. Engineering tests showed that a compact nickel metal hydride battery provided sufficient power for over 12 hr of continuous operation for the MIMOS instruments.

Acknowledgment: Funded by German space agency DLR under contract 50 QX 0603 and 50QX0802.

References:

- [1] I.L. ten Kate et al., in: *J. Aerosp. Eng.* 26 (2012) 183-196.
- [2] Klingelhöfer et al., *J. Geophys. Res.* 108(E12) (2003), doi: 10.1029 / 2003JE002138.
- [3] Klingelhöfer et al., *Science* 306 (2004), 1740-1745.
- [4] Morris et al., *Science* 305 (2004), 833-836.
- [5] Morris et al., *J. Geophys. Res.* 111 (2006), doi:10.1029/2006JE002791.
- [6] P. Lechner et al., *Nucl. Instr. and Meth. A* 377 (1996), 346-351.
- [7] M. Blumers et al., *Nucl. Instr. and Meth. A* (2010), doi: 10.1016/j.nima.2010.04.007.